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# Primordial pollution of globular clusters within their host dwarfs embedded in dark matter halos at high redshifts

Kenji Bekki[1]⋆
[1]*School of Physics, University of New South Wales, Sydney 2052, NSW, Australia*

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**ABSTRACT**

Recent observational studies have revealed star-to-star abundance inhomogeneity among light elements (e.g., C, N, O, Na, and Al) of stars on the main sequence in the Galactic globular clusters (GCs). One of promising interpretations for this result is that the observed abundance inhomogeneity is due to the second generation of stars formed from ejecta of the first generation of evolved stars (e.g., AGB stars) within GCs. However it remains unclear whether and how this primordial pollution can occur within GCs. We here propose a new scenario in which primordial pollution of GCs is highly likely to occur if GCs are located in the central regions of high redshift dark matter subhalos that can host low-mass dwarf galaxies. In this scenario, gas ejected from the first generation of stars of GCs can be effectively trapped in the deep gravitational potential of their host halos and consequently can be consumed for the formation of the second generation of stars without losing a significant amount of gas by ram pressure stripping of interstellar and intergalactic medium. During merging of these halos with the proto-Galaxy, the halos are completely destroyed owing to the strong tidal field of the Galaxy. The self-polluted GCs located initially in the central regions of the halos can survive from tidal destruction owing to their compactness and finally become the Galactic halo GCs. In this scenario, ejecta of field stars surrounding the central GCs can be also converted into stars within their host dwarfs and finally become the second generation of stars of GCs. We also discuss the origin of the difference in the degree of abundance inhomogeneity between different GCs, such as $\omega$ Centauri and NGC 6752, in terms of the difference in physical properties between host halos from which GC originate.

**Key words:** globular clusters: general – globular clusters:individual ($\omega$ Centauri)– globular clusters:individual (NGC 6752)– galaxies: star clusters – galaxies:evolution – galaxies:stellar content

## 1 INTRODUCTION

The origin of star-to-star abundance inhomogeneity observed in the Galactic globular clusters (GCs) has long been discussed based mainly on the following two working hypotheses: The primordial hypothesis and the mixing one (e.g., Cottrell & Da Costa 1981; Freeman & Norris 1981; Smith 1987; Suntzeff 1993; Kraft 1994; Gratton et al. 2004). The first hypothesis is that the observed inhomogeneity is due to the second generation of stars that were formed from gas ejected from the first generation of evolved stars (e.g., AGB stars) of GCs ("primordial pollution" scenario, e.g., Cottrell & Da Costa 1981). The second is that the observed chemical inhomogeneity of GCs can result from *internal processes* of stars, such as dredge-up of CN-processed material from inner hydrogen-burning regions (e.g., Smith 1987; Kraft 1994). Recent observational studies of stellar abundance of some Galactic GCs have revealed star-to-star abundance inhomogeneity among less evolved stars on the main sequence, where deep mixing of chemical components are highly unlikely (e.g., Cannon et al. 1998 for 47 Tuc). These studies accordingly suggested that the primordial pollution scenario is more promising than the mixing (or evolutionary) scenario (Da Costa et al. 2004; Gratton 2004 for a recent review).

One of key questions related to the primordial pollution scenario is whether and how ejecta mainly from AGB stars of the first generation of stars can be effectively trapped within GCs and consequently converted into the second generation of stars. Frank & Gisler (1976) showed that gas of GCs can

⋆ E-mail: bekki@bat.phys.unsw.edu.au

be efficiently stripped by ram pressure of the Galactic halo gas for most GCs. Smith (1996) suggested that the stellar ejecta from the first generation of stars are likely to be lost entirely from GCs with small binding energies through energetic outflow of intracluster wind. Gnedin et al. (2002) demonstrated that $\omega$ Cen could not enrich itself with heavy elements of AGB stars owing to efficient ram pressure stripping of the Galactic interstellar medium (ISM), if it formed and evolved in isolation. These previous studies thus appear to suggest that primordial pollution is not likely within GCs evolving in isolation, though numerical attempts have not yet been made to investigate the details of primordial pollution processes within GCs.

Recent numerical simulations have suggested that GCs can be formed in the central regions of dwarf galaxies embedded by low-mass dark matter halos (e.g., Bromm & Clarke 2002; Mashchenko & Sills 2005). Both observational and theoretical studies of GCs suggested that massive globular clusters such as $\omega$ Cen and G1 were previously stellar nuclei (or nuclear star clusters) of nucleated dwarf galaxies (e.g., Freeman 1993; Bekki & Freeman 2003; Bekki & Chiba 2004). Owing to the deeper gravitational potential in the central regions of dark matter halos, primordial pollution processes can be quite different between GCs evolving in isolation and those in the nuclear regions of their host halos. Thus it is quite important and timely to discuss whether and how primordial pollution of GCs can proceed *if GCs are within the central regions of low-mass dark matter halos that can host dwarf galaxy populations.*

The purpose of this Letter is to propose a new scenario in which primordial pollution can proceed very efficiently in GCs that are located in nuclear regions of their host halos at high redshifts. In this scenario, primordial pollution can proceed more efficiently in the nuclear GCs than in those evolving in isolation, because the ejecta of AGB stars are more effectively trapped in GCs (without being significantly lost through ram pressure stripping and energetic outflow of evolved stars) owing to the deeper gravitational potential of their host halos. The nuclear, self-polluted GCs can appear as the Galactic halo GCs when the host halos merge with the proto-Galaxy and are subsequently destroyed by the strong tidal field of the Galaxy (i.e., when field stars and dark matter halos surrounding the GCs are all removed by the tidal stripping).

We firstly show the three advantages of this scenario in explaining why ejecta of the first generation of stars can be effectively trapped and converted into stars. Then we discuss the origin of the difference in the degree of abundance inhomogeneity between GCs in the Galaxy in the context of the proposed chemical pollution scenario. Since many authors have already discussed advantages and disadvantages of the primordial pollution (or enrichment) processes *within isolated proto-GC clouds and GCs* (e.g., Cayrel 1986; Parmentier & Gilmore 2001; Thoul et al. 2002; Recchi & Danziger 2005), we here do not intend to discuss these points.

## 2 THREE ADVANTAGES OF CHEMICAL POLLUTION WITHIN SUBHALOS

In the present study, we adopt an AGB pollution scenario (e.g., Smith & Norris 1982) in which the second generation of stars originate from AGB ejecta only after gas ejected from Type II supernovae (SNe II) were removed from the systems owing to much more energetic processes of SNe II (with the wind velocities of an order of $\sim$ 1000 km s$^{-1}$). Progenitor stars of SNe II are considered to have masses of $M > 10$M$_\odot$ (e.g., Woosley & Weaver 1995) and thus have shorter lifetimes than AGB progenitor stars with $0.8 < (M/\mathrm{M}_\odot) < 8$ (e.g., van den Hoek & Groenewegen 1997). Therefore the above assumption on the star formation from AGB ejecta only after the completion of SNe II events is regarded as reasonable. It is expected that the first and the second generations of stars are different with each other not in heavier elements (e.g., Fe) but in CN-processed ones owing to the selective self-enrichment. Although this scenario has several problems in explaining *quantitatively* the observed abundance pattern (e.g., C and O) in GCs (e.g., Smith & Norris 1982), we adopt this in order to more clearly demonstrate the advantages of the chemical pollution of GCs within dwarfs embedded in subhalos.

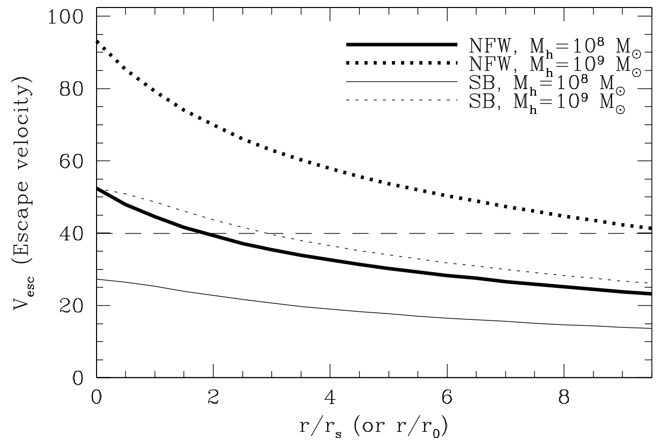


**Figure 1.** The radial dependences of the escape velocities ($V_{\rm esc}$) for four different models: the SB model with $M_{\rm h} = 10^8$M$_\odot$ and $r_0 = 0.48$ kpc (thick solid), the SB one with $M_{\rm h} = 10^9$M$_\odot$ and $r_0 = 1.28$ kpc (thick dotted), the NFW model with $M_{\rm h} = 10^8$M$_\odot$ and $r_{\rm s} = 0.16$ kpc (thin solid), and the NFW one with $M_{\rm h} = 10^9$M$_\odot$ and $r_{\rm s} = 0.52$ kpc (thin dotted). For comparison, the maximum value of the wind velocity of AGB stars is shown by a dashed line.

### 2.1 Trapping AGB ejecta

By investigating whether the terminal (or expansion) velocity ($V_{\rm w}$) of the stellar wind of AGB stars can be smaller or larger than the escape velocity ($V_{\rm esc}$) of a halo (or a GC), we can discuss whether the ejecta from AGB stars can be trapped within the GC for a times scale long enough for star formation of the second generation of stars (e.g., Smith 1996). The observed $V_{\rm w}$ ranges roughly from 2 km s$^{-1}$ to 40 km s$^{-1}$ in Loup et al. (1993) whereas Dupree et al. (1992) found evidences of AGB winds with $V_{\rm w}$ = 90 km s$^{-1}$. In this paper, we discuss whether $V_{\rm esc}$ of a dark matter halo can be smaller or larger than the possibly maximum value of $V_{\rm w}$ = 40 km s$^{-1}$ (hereafter referred to as $V_{\rm w,max}$). In order to show the dependences of $V_{\rm esc}$ of low-mass halos with different masses ($M_{\rm h}$) more clearly, we do not intend to derive $V_{\rm w}$ for the combined mass distributions of halos and GCs.

For comparison, we adopt the two different profiles of dark matter halos at high redshifts: (1) The "SB" profiles with large cores proposed by Salucci & Burkert (2000) and (2) the "NFW" ones with cuspy cores predicted from the standard cold dark matter (CDM) cosmogony (Navarro, Frenk, & White 1996). The SB profiles consistent with the observed rotation curves of galaxies are described as:

$$\rho_{\rm sb}(r) = \frac{\rho_{\rm sb,0}}{(r+r_0)(r^2+r_0)^2}, \tag{1}$$

where $\rho_{\rm sb,0}$ and $r_0$ are the central dark matter density and the core (scale) radius, respectively. For the SB profile, the dark matter core parameters, $\rho_{\rm sb,0}$, $r_0$, and $M_0$ (where $M_0$ is the total dark matter mass within $r_0$) are not free parameters, and clear correlations are observed between them (Salucci & Burkert 2000):

$$M_0 = 4.3 \times 10^7 (\frac{r_0}{\rm kpc})^{7/3} M_{\odot}. \tag{2}$$

The NFW profile is described as:

$$\rho(r) = \frac{\rho_s}{(r/r_{\rm s})(1+r/r_{\rm s})^2}, \tag{3}$$

where $r$, $\rho_s$, and $r_{\rm s}$ are the distance from the center of the cluster, the characteristic density, and the scale-length of the dark halo, respectively. Fig. 1 shows the radial dependences of $V_{\rm esc}$ calculated for the SB model with $M_{\rm h} = 10^8 {\rm M}_{\odot}$ and $r_0 = 0.48$ kpc, the SB one with $M_{\rm h} = 10^9 {\rm M}_{\odot}$ and $r_0 = 1.28$ kpc, the NFW model with $M_{\rm h} = 10^8 {\rm M}_{\odot}$ and $r_{\rm s} = 0.16$ kpc, and the NFW one with $M_{\rm h} = 10^9 {\rm M}_{\odot}$ and $r_{\rm s} = 0.52$ kpc. These values of the NFW models are derived by using the lowest mass model in the NFW with a mass-size scaling of $M_{\rm h} \propto {r_{\rm s}}^2$ reasonable for the CDM halos.

As shown in Fig. 1, $V_{\rm esc}$ both for the two NFW models are significantly larger than $V_{\rm w,max}$ in the nuclear regions with $r/r_{\rm s} < 1$, which suggests that ejecta of AGB stars can be more effectively trapped in nuclear regions of the halos compared with their outer ones. The difference between $V_{\rm esc}$ and $V_{\rm w,max}$ at $r/r_{\rm s} < 1$ (or $r/r_0 < 1$) is larger in the more massive model ($M_{\rm h} = 10^9 {\rm M}_{\odot}$) than in the less massive one ($M_{\rm h} = 10^8 {\rm M}_{\odot}$) both for the NFW and the SB models. This result implies that ejecta of AGB stars can be more effectively trapped in more massive halos and thus that primordial pollution can proceed more efficiently in more massive halos. The higher $V_{\rm esc}$ at a given radius for a given $M_{\rm h}$ in the NFW models in comparison with the SB models suggests that inner density profiles of dark matter halos can be an important parameter which determines the details of primordial pollution processes.

Since the mass densities ($\rho_{\rm h}$) of halos virialized at redshift $z$ are roughly proportional to (1+z)$^3$ (Padmanabhan 1993), $V_{\rm esc}$ can be larger in halos formed at higher redshifts for a given halo mass (i.e., $V_{\rm esc} \propto ({M_{\rm h}}^2 \rho_{\rm h})^{1/6} \propto (1+z)^{1/2}$ for a given $M_{\rm h}$). This suggests that ejecta of AGB stars can be more effectively trapped in halos formed at higher redshifts for a given mass: Primordial pollution of GCs can more efficiently proceed in nuclear regions of halos formed at higher redshifts.

### 2.2 Suppression of ram pressure stripping

Gas within GCs can be stripped if the following inequality is satisfied:

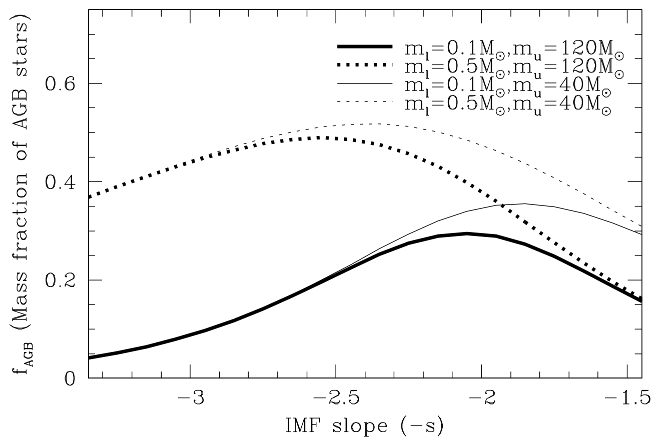


**Figure 2.** The dependences of the mass fraction of stars with masses ranging from 1M$_{\odot}$ to 8M$_{\odot}$ (i.e., progenitors of AGB stars) on the slopes of IMF (initial mass function) with $-3.5 \le -s \le -1.5$ in GCs for four different models with $m_{\rm l} = 0.1{\rm M}_{\odot}$ and $m_{\rm u} = 120{\rm M}_{\odot}$ (thick solid), with $m_{\rm l} = 0.5{\rm M}_{\odot}$ and $m_{\rm u} = 120{\rm M}_{\odot}$ (thick dotted), with $m_{\rm l} = 0.1{\rm M}_{\odot}$ and $m_{\rm u} = 40{\rm M}_{\odot}$ (thin solid), and with $m_{\rm l} = 0.5{\rm M}_{\odot}$ and $m_{\rm u} = 40{\rm M}_{\odot}$ (thin dotted). If we assume that ejecta of only more massive AGB stars with the masses of $6-7{\rm M}_{\odot}$ can be used for star formation, $f_{\rm AGB}$ is much smaller than those shown in this figure (Bekki & Norris 2005).

$$\rho_{\rm ISM} {v_{\rm rel}}^2 > 2\pi G \Sigma_s \Sigma_g, \tag{4}$$

where $\rho_{\rm ISM}$ is the density of interstellar gas in halos or disks, $v_{\rm rel}$ is the relative velocity between a GC and the interstellar gas, $G$ is the gravitational constant, $\Sigma_s$ is the gravitational surface mass density, and $\Sigma_g$ is the surface density of intracluster gas (e.g., ejecta of AGB stars). By using the formula essentially the same as the above equation (4), Frank & Gisler (1976) showed that $\rho_{\rm ISM}$ required for the sweeping of gas within the central regions of most GCs is $5 \times 10^{-3}$ cm$^{-3}$ for $v_{\rm rel}$ = 200 km s$^{-1}$, $\Sigma_s = 10^4$ M$_{\odot}$ pc$^{-2}$, and a reasonable value of the specific mass loss rate (used for the estimation of $\Sigma_g$). The typical mass and tidal radius ($r_{\rm t}$) of GCs are $5 \times 10^5 {\rm M}_{\odot}$ and 50 pc, respectively, (Binney & Tremaine 1987). This means that mean $\Sigma_s$ within $r_{\rm t}$ is by a factor of $\sim 20$ smaller than the above central value and thus $\rho_{\rm ISM}$ required for the sweeping of the outer gas is $2.5 \times 10^{-4}$ cm$^{-3}$.

It should be noted here that the derived values of $\rho_{\rm ISM}$ are much smaller than a typical value of the number density of H near the Sun ($n_{\rm H} \sim 1{\rm cm}^{-3}$). The total mass of dark matter within the central 50 pc (= $r_{\rm t}$) of the halo in the NFW model with $M_{\rm h} = 10^9 {\rm M}_{\odot}$ is $2.8 \times 10^6 {\rm M}_{\odot}$, which means that $\Sigma_s$ can be significantly larger in GCs located in nuclear regions of the halo than in isolated GCs. This suggests that ram pressure stripping is much less effective in sweeping gas of GCs if GCs are located in nuclear regions of halos. Although nuclear GCs of halos can keep their gas from been stripped by the Galactic halo gas, the surface gravity from their host halos appears to be not strong enough to prevent gas from being swept by the ISM of the Galactic disk with $n_{\rm H} \sim 1{\rm cm}^{-3}$.

### 2.3 Increase of the total amount of AGB ejecta

In order to estimate the mass fraction ($f_{\rm AGB}$) of AGB progenitor stars with the masses ranging from $1{\rm M}_{\odot}$ to $8{\rm M}_{\odot}$ in a GC with the total mass of $M_{\rm cl}$, we assume an initial mass function (IMF) in number described as $\psi(m_{\rm I}) = A{m_{\rm I}}^{-s}$, where $m_{\rm I}$ is the initial mass of each individual star and the slope of $s = 2.35$ corresponds to the Salpeter IMF. The normalization factor $A$ is a function of $M_{\rm cl}$, $m_{\rm l}$ (lower mass cut-off), and $m_{\rm u}$ (upper one):

$$A = \frac{M_{\rm cl} \times (2-s)}{{m_{\rm u}}^{2-s} - {m_{\rm l}}^{2-s}}. \tag{5}$$

where $m_{\rm l}$ and $m_{\rm u}$ are regarded as free parameters in the present study.

Fig. 2 shows the dependences of $f_{\rm AGB}$ on the IMF slope ($s$) for four different sets of parameters of $m_{\rm l}$ and $m_{\rm u}$. $f_{\rm AGB}$ is at most $\sim 0.5$ in these models. The mass fraction ($f_{\rm 2nd}$) of the second generation of stars is described as,

$$f_{\rm 2nd} \propto \epsilon_{\star} \times m_{\rm ej} \times f_{\rm AGB}, \tag{6}$$

where $\epsilon_{\star}$ is the star formation efficiency of star-forming gas and $m_{\rm ej}$ is the mass ratio of gas ejected from AGB stars to initial stellar masses of progenitors of AGB stars. $\epsilon_{\star}$ is observed to range from $\sim 0.01$ (Duerr et al. 1982 for the $\lambda$ Sco complex) to $\sim 0.4$ (Wilking & Lada 1983 for the $\rho$ Oph cloud). If we adopt the table value of $m_{\rm ej}$ (=0.46) for AGB stars with $m_{\rm I} = 1{\rm M}_{\odot}$ and $Z = 0.001$ in van den Hoek & Groenewegen (1997), we can find that $f_{\rm 2nd}$ is at most 0.12 ($= 0.5 \times 0.4 \times 0.46$).

The derived maximum value of $f_{\rm 2nd} = 0.12$ is significantly smaller than 0.5 that is required for explaining the observed number ratio of CN-strong stars to CN-weak ones for NGC 6752 in the context of the primordial pollution scenario (e.g., Smith & Norris 1982). Although $f_{\rm 2nd}$ required for explaining abundance inhomogeneity may well be different between different clusters (thus smaller $f_{\rm 2nd}$ is still acceptable for some GCs), the derived small values of $f_{\rm 2nd}$ imply that if we assume that the second generation of stars are formed from the first one *initially within GCs,* the primordial pollution scenario can not explain quantitatively the observed abundance inhomogeneity of GCs.

However, if GCs are located in nuclear regions of dark matter halos hosting dwarf galaxies, the ejecta of field stellar populations (i.e., major components of the dwarfs) surrounding the nuclear GCs can be fueled into the nuclear regions and converted into new stars there. If a large amount of gas ejected from the surrounding stellar populations can be converted into the second generation of stars within GCs, the mass fraction of the second generation can be significantly boosted up: We do not have to assume an extreme set of parameter values for IMF and $\epsilon_{\star}$ in explaining the observed $f_{\rm 2nd}$ (See Smith & Norris 1982 for this problem of unusual IMF required for the primordial pollution scenario).

## 3 DISCUSSIONS AND CONCLUSIONS

### 3.1 Defunct dwarfs as GC hosts

A key question in this scenario is whether GC host dwarfs embedded in dark matter halos can be completely destroyed by the strong Galactic tidal field without the central GCs being destroyed. Recent numerical simulations have demonstrated that nuclear star clusters can survive from the strong tidal field of the Galaxy owing to their initial compactness whereas the main bodies of (nucleated) dwarfs are completely destroyed and dispersed into the Galactic halo region (e.g., Bekki & Freeman 2003; Tsuchiya et al. 2003). Previous simulations also showed that nucleated dwarfs can be more efficiently converted into massive star clusters (i.e., naked nuclei) under strong tidal field of groups and clusters of galaxies for the SB profiles of dark matter halos (Bekki et al. 2003). These theoretical works therefore strongly suggest that the present scenario is promising.

Recent abundance studies of stars both for the Galactic halo and for dwarfs (e.g., dwarf spheroidal, dSph) in the Local Group have revealed that [$\alpha$/Fe] ratios of most stars in the dwarfs are generally lower than similar metallicity Galactic halo stars (e.g., Venn et al. 2004). The higher [$\alpha$/Fe] ratios of the Galactic halo can be due to *very early merging of low-mass dwarf galaxies*, which were destroyed to form the Galactic halo without efficient chemical enrichment of stars (Venn et al. 2004). We propose that these dwarfs destroyed in the very early history of the Galaxy (i.e., defunct dwarfs) are host galaxies of the Galactic halo GCs with abundance inhomogeneity. This proposal is consistent with the observed higher [$\alpha$/Fe] ratios in the Galactic GCs (e.g., Freeman 1993).

### 3.2 Diversity in primordial pollution processes

Smith (1987) divided GCs into three classes according to (1) whether star-to-star abundance inhomogeneity can be seen for Fe-peak element and (2) whether it can be seen in CN abundance (i.e., whether GCs show bimodal CN distributions). It was found in Smith (1987) that (1) only $\omega$ Cen and M22 show inhomogeneity in Fe-peak elements, (2) GCs with no bimodal CN distributions have lower metallicities of $-2.2 \le$ [Fe/H] $\le -1.6$ (e.g., M92 and M15), and (3) GCs with bimodal CN distributions have higher metallicities of [Fe/H] $> -1.6$ (e.g., NGC 6752 and 47 Tuc). However it remains unclear why $\omega$ Cen shows such inhomogeneity in Fe-peak element.

The present study can provide the following answer for the above question, by assuming that the observed inhomogeneity is solely due to the primordial pollution processes of GCs. $\omega$ Cen was formed in the nuclear region of a massive subhalo ($\sim 5 \times 10^8 {\rm M}_{\odot}$) that was virialized at very high redshift ($z \sim 15$) and was more massive than any other subhalos hosting the Galactic GCs at that redshift. This massive halo with a higher mass density (due to earlier virialization) could not be soon destroyed by the proto-Galactic tidal field because of its stronger self-gravity, and consequently star formation could continue for a longer time scale in its nuclear region. As a result of this, not only AGB ejecta but also some fraction of metal-enriched gas from Type II and Type Ia supernovae could be finally recycled and converted into new generations of stars within the $\omega$ Cen's host halo. The initially large apocenter distance of its orbit, for which a longer time scale of dynamical friction is required for the $\omega$ Cen's host to reach the Galactic central region, can be also responsible for the prolonged star formation activity (Bekki & Freeman 2003).

Less massive halos containing GCs (e.g., NGC 6752)

other than $\omega$ Cen had shallower gravitational potential and were more easily destroyed by the tidal field of the proto-Galaxy in their earlier histories. Only ejecta from more massive AGB stars with smaller wind velocities (an order of $\sim 10$ km s$^{-1}$) therefore could be converted into new stars to become the second generation of stars in GCs without efficient chemical enrichment (i.e., without significant metallicity spread) due to SNe II with very large wind velocities (an order of $\sim 1000$ km s$^{-1}$). Less massive halos with smaller pericenter and apocenter distances of their orbits would not have experienced efficient chemical pollution of GCs owing to more rapid destruction of the halos. Thus $\omega$ Cen can show abundance inhomogeneity both in heavier elements (e.g., Fe) and in light ones (e.g., C, N, and O) whereas other GCs can show abundance inhomogeneity only in light ones.

### 3.3 External pollution scenario

We have shown that the AGB ejecta can be retained in the central regions of their host dwarfs and consequently converted into stars that finally become the second generation of stars in GCs. We also have suggested that AGB ejecta of field stellar populations surrounding the nuclear GCs can be converted into stars to become the second generation of stars in GCs. Accordingly, it would be reasonable to say that "external pollution" (or modified version of the original primordial pollution scenario) rather than "self-pollution" is a more reasonable jargon that denotes the chemical pollution processes of GCs in the central regions of dwarfs. This external pollution scenario may well explain not only the observed helium overabundance of $\omega$ Cen (Bedin et al. 2004) but also the large fraction of CN-strong stars in GCs with abundance inhomogeneity (Bekki & Norris 2005).

One of potential problems of this external scenario is that the physical mechanism for the selective pollution by AGB stars (not by SNe II) is not clearly understood. In order to discuss this point, we plan to investigate gas dynamics within the central $0.1 - 100$pc of dwarfs at very high redshifts by using chemodynamical simulations combined with the latest results of AGB yields derived by Campbell et al. (2005). It is also our future study to investigate whether this scenario can explain the observed O-Na and Mg-Al anticorrelations of GCs. Smith & Norris (1982) suggested that if both the first and the second generations of stars are formed from ejecta of AGB stars with different mases, the observed CN-bimodality in GCs can be explained. This modified primordial (and external) pollution scenario will be addressed by our future chemodynamical simulations in a more quantitatively.

Theoretical studies based on cosmological simulations have just started extensive investigation on structural and kinematical properties of GC systems of galaxies in a $\Lambda$CDM Universe (e.g., Bekki 2005; Yahagi & Bekki 2005). These Mpc-scale simulations, combined with sub-pc scale ones on star formation within GCs, will provide more robust predictions on spatial distributions and kinematics of the Galactic GCs with different past histories of primordial pollution processes and thus be compared with corresponding observations (e.g., Carretta 2005).

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